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Perspective

Conservation lessons from Cuba: Connecting science and policy

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ABSTRACT

The island of Cuba and surrounding cays are a major repository of biodiversity in the Caribbean archipelago. Although Cuba is widely recognized for its high biodiversity and endemism, much of the country's conservation experiences have been overlooked by the global conservation scientific community. Here we particularly highlight decades of governance efforts that built and strengthened forest and biodiversity protection policies, resulting in the second largest rate of forest cover recovery worldwide, doubling of both marine and terrestrial protected area networks in recent years, as well as developing a unique agroecological matrix management. These conservation strategies combined with the constraints on infrastructure development as a result of the decades long U.S. embargo, has had the indirect result of placing Cuba in a unique position in the Caribbean region. Nevertheless, despite these advances, significant part of the Cuban biota suffers from deforestation and habitat degradation. Major threats include booming tourism, spread of introduced species, climate change and increasing frequency and intensity of storms and hurricanes associated to global warming. We also point out for Cuba's future challenges, as well as lessons that could be applied in other tropical countries.

1. Introduction

Cuba is the largest of the Caribbean islands, harboring the greatest number of species in the West Indies (Eduardo, 1991), and a global biodiversity hotspot (Myers et al., 2000). In spite of this, its biodiversity resources as well as conservation initiatives have been somewhat overlooked by the conservation community and in the scientific literature, in large part because of the political and economic embargo by the US and diplomatic conflicts between those two countries.

According to the International Union for Conservation of Nature (IUCN), Cuba accounts for the second largest number of threatened marine fishes (35) and mammals (17), as well as the third largest number of birds (14) and plants (176) in the Caribbean basin (Fig. 1). Cuba ranks 39th in the world among species-rich countries based on records of amphibians, birds, mammals, reptiles and vascular plants species (UNEP-WCMC, 2004). Moreover, Cuba harbors the greatest degree of species that are endemic in the West Indies. Over 50% of its plants, 32% of its vertebrates (Mugica, 2009) and 95% of its amphibians are unique to this region (Fong et al., 2015).

Cuba's wildlife includes some of the world's smallest birds (*Mellisuga belenae*), bats (*Nystiellus lepidus*) and frogs (Estrada and Hedges, 1996). Other noteworthy species are the blind cave fishes (*Lucifuga* sp.), and arboreal leaf-eating rodents (*Capromys pilorides*) (Eduardo, 1991). Among the Cuban plants, the highly threatened *Microcyca* is the only gymnosperm genus endemic to the Caribbean Islands (Stevenson, 1992) and the Cuban Oak (*Quercus sagraena*) is one of the few oak species found in the tropics (Cavender-Bares et al., 2015).

Of its four extinct birds, which have disappeared since the Spanish colonization, the Cuban macaw was one of the world's smallest macaws. It became extinct in the beginning of the 19th century, although it was very common in the early 1500s, as noted by Christopher Colombus (Wiley and Kirwan, 2013).

According to the Global Information Systems for Coral Reefs, Cuba also has the most extensive insular coral reef of the Caribbean Sea, with an area totalling 329,000 ha which supports more than 465 coral fish species (Reefbase, 2016).These ecosystems contain six to eight times more fish biomass per area unit than other Caribbean reefs (Pennisi, 2015).

Cuba harbors the greatest area of wetland ecosystems in the Caribbean archipelago. Approximately 13.4% of the Cuban territory is covered by wetlands, encompassing approximately 1.5 million hectares, including mangroves, flooded savannas, peatlands, freshwater swamp

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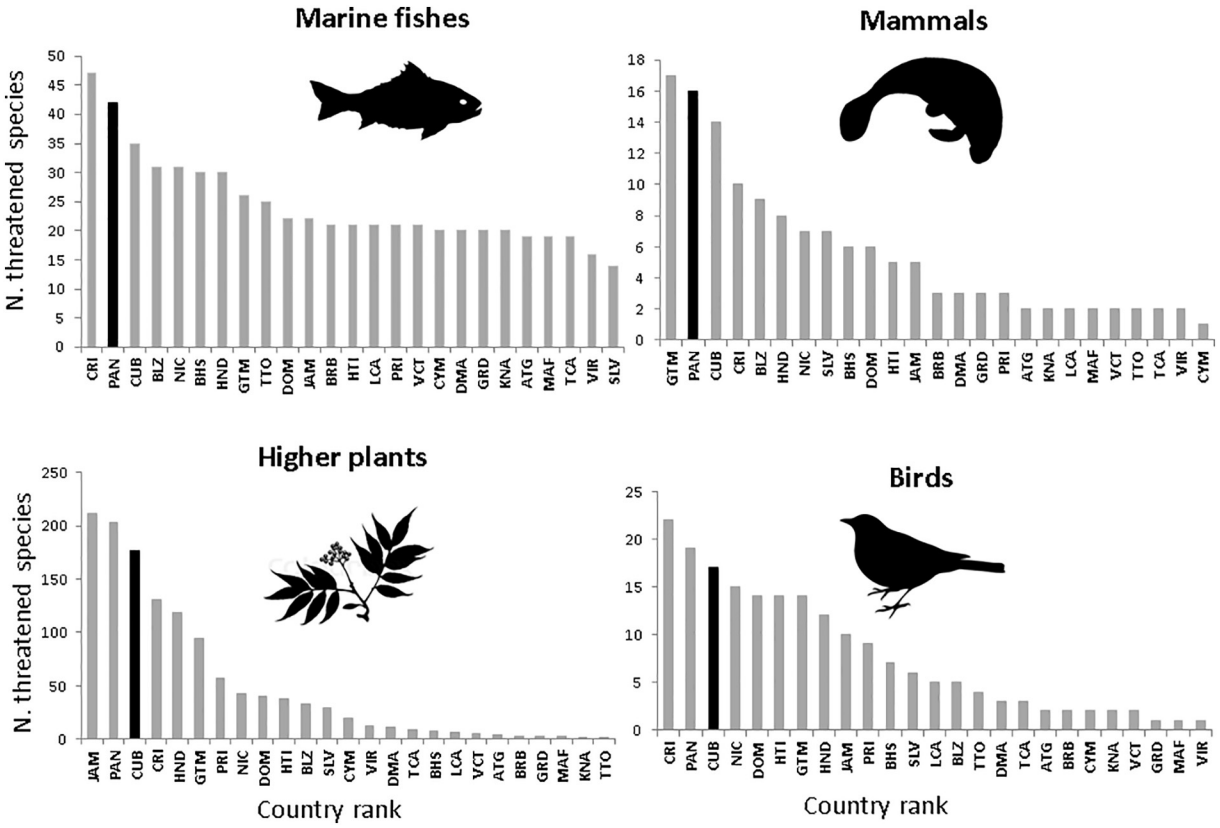
Marine fishes
N. threatened species
CRI PAN CUB BLZ NIC BHS HND GTM TTO DOM JAM BRB HTI LCA PRI VCT CYM DMA GRD KNA ATG MAF TCA VIR SLV
Mammals
GTM PAN CUB CRI BLZ HND NIC SLV BHS DOM HTI JAM BRB DMA GRD PRI ATG KNA LCA MAF VCT TTO TCA VIR CYM
Higher plants
N. threatened species
JAM PAN CUB CRI HND GTM PRI NIC DOM HTI BLZ SLV CYM VIR DMA TCA BHS LCA VCT ATG BRB GRD MAF KNA TTO
Country rank
Birds
CRI PAN CUB NIC DOM HTI GTM HND JAM PRI BHS SLV LCA BLZ TTO DMA TCA ATG BRB CYM KNA VCT GRD MAF VIR
Country rank

Fig. 1. Number of threatened species of marine fishes, higher plants, mammals and birds according to the IUCN in Central America and Caribbean countries. ATG – Antigua Barbuda; BHS – The Bahamas; BRB – Barbados; CYM – Cayman Islands; CUB – Cuba; DMA – Dominica; DOM – Dominican Republic; GRD – Grenada; HTI-Haiti; JAM – Jamaica; PRI – Puerto Rico; KNA – St. Kitts and Nevis; LCA – St. Lucia; MAF -St. Martin (French part); TTO – Trinidad and Tobago; TCA – Turks and Caicos Island; VIR – Virgin Islands (U.S.); BLZ – Belize; CRI – Costa Rica; SLV – El Salvador; GTM – Guatemala; HND – Honduras; NIC – Nicaragua; PAN – Panama.

forests and various types of managed wetlands (Borhidi et al., 1993). Approximately 30% of Cuban wetlands are included in the national system of protected areas. Some important wetlands of Cuba include the Birama marshes in Granma province, Río Máximo wildlife refuge in Camagüey province, and the Lanier Swamp in the Isla de la Juventud (Isle of Youth). The Zapata Swamp with a total area of 45,000 ha is the largest and most complex drainage system in the Caribbean (Kirkconnell et al., 2005). Some 625,000 ha of the Zapata Swamp complex are protected as a Biosphere Reserve.

Despite of all the difficulties in doing science "in from the cold" and the complexity of diplomatic ties with other countries (Stone, 2015), Cuba's scientific and governance advances have prevailed. An increasing number of international institutions, including some from the United States, are building partnerships in Cuba (Garcia, 2015). Examples of such include the Smithsonian Institution, Wildlife Conservation Society, Cornell Ornithology Laboratory, American Museum of Natural History, The Nature Conservancy, Mote Marine Laboratory, University of Florida, Environmental Defense Fund, Center for Marine Conservation, Harte Research Institute, Ocean Foundation and the New York Botanical Gardens.

Cuba is an active participant in the Caribbean Biological Corridor of the United Nations Environmental Programme (UNEP), collaborating in a series of actions aimed at long-term biodiversity protection, environmental rehabilitation and improving livelihoods (http://www.unep.org/stories/Ecosystems/Caribbean-Biological-Corridor.asp). Recently, the US National Oceanic and Atmospheric Administration and the US National Park Service signed a memorandum of understanding with Cuba's Ministry of Science, Technology, Stewardship and Management for cooperation in the area of marine protection policy (NOAA, 2015; www.noaanews.noaa.gov/stories2015/111815-us-and-cuba-to-cooperate-on-conservation-and-management-of-marine-protected-areas.html). Furthermore, Cuba is a recognized global leader in the development of sustainable agricultural practices, particularly regarding agroecology and organic low input systems (Levins, 1993; Altieri et al., 1999; Nelson et al., 2009; Altieri and Funes-Monzote, 2012). The World Wildlife Fund recognizes Cuba as one of the countries with the smallest ecological footprint, while maintaining fairly high levels of human development (Cabello et al., 2012).

In this paper, we present a timeline of environmental governance in Cuba (Section 2), highlight Cuban unique agroecology experiences (Section 3), describe the nationwide forest regrowth (Section 4), review conservation advances (Section 5) and major challenges for preserving biodiversity in the island (Section 6). Finally we call for the application of conservation lessons from Cuba in other developing nations (Section 7).

2. Historical background and environmental governance

Table 1 outlines the timeline of environmental governance actions by Cuba in various areas including environment, conservation and forestry along with the historical background. Through the first half of the 1900's, Cuba followed a similar historical path as its neighbors, with an economy based on agriculture commodity exports such as tobacco and sugarcane, and close diplomatic and trade relationships with the United States (Levins, 1993). Large tracts of natural habitats had been converted to monoculture plantations after Spanish colonization and by 1959, forested area had declined from 72% to 14% of Cuba (Díaz-Briquets, 1996).

Sierra del Cristal, Cuba's first national park, was established in 1930 and three additional national parks were added during this decade. However, only two additional parks were established from 1940 to 1959 (Eduardo, 1991). The Cuban revolution came about in 1959; five

Table 1
Timeline of the Cuban sustainability, forestry and biodiversity conservation governance and practices.

	Policy	Sustainability	Forestry	Biodiversity conservation
1930s to 1950s	Diplomatic relationship and trade with US	Rural society dependent on natural resources, such as fuel wood	Forest loss, conversion into sugar cane and tobacco plantations	Pico Cristal Park, the first protected area in Cuba, is created in 1930 Five other parks are created until 1959
1959	Socialist revolution	Industrialized agriculture using large quantities of external outputs	Reforestation Plan using exotics	Nine parks are established in April 1959 Beginning of the captivity breeding program of the Cuban Crocodile at the Zapata Swamp
1970s	Cold war Trade with USSR		National Forest Policy	In 1975, 10 new parks are created
1980's		Creation of the Law 33 which regulates the use of natural resources (water, soil and mineral resources) in 1981 Government guidance to generalized use of organoponics in 1987		First national ecology conference creation of the Council on Natural Resources and the Environment Law 81 aiming at protecting 25% of the Cubans lands and water
1989	Fall of the Berlin wall and end of the USSR	Decrease in petroleum based agricultural inputs		
1990's	Special Period	Nationwide agroecological conversion Creation of the Environmental Education National Plan	Cuban Forest Law implemented Urgent measures against illegal logging Creation of the CITMA	Law 81 aiming at protecting 25% of the Cubans lands and water Castro's speech at Rio Summit 92 Creation of more than 30 new protected areas Decree Law 201-99 on Cuba's National System of Protected Areas (SNAP) Consolidation of the SNAP
2000's		Wide use of low input agriculture Environmental Education Plan (2010–2015)	Cubans public forestry institution counts with 2619 professionals, which accounts for more than the sum all other Caribbean nations (GFRA, 2010)	Increase of 2.8% to 7.6% in marine and 6.3% to 12.5% terrestrial protected network from 2009 to 2010, respectively (IUCN). V National Report on the Convention of Biological Diversity in 2014
2015	Obama reestablishes diplomatic relationships			National Plan for the Conservation and Management of Chondrichthyes
2017	Trump announces new restrictions and reversing of the ties between the two countries The U.S. State Department withdraw diplomats from US embassy in Cuba			

Table 2
2010 annual industrial fertilizer consumption and green-house gases produced by farming per country agricultural area (tons/ha) in Central America and Caribbean region – CACR; in Cuba and the Cuban rank (from low to high values) and the number of countries considered (total n) (FAOSTAT).

Inputs/emissions related to farming	Cuba	CACR mean (s.d.)	Rank (total n)
Phosphate	5.23	13.3 (12.1)	5 (15)
Potash	7.7	11.26 (15.38)	11 (15)
Nitrogen	7.1	17.2 (12.9)	4 (16)
CO_2	1.53	2.06 (1.52)	14 (31)
CH4	1.04	1.17 (0.93)	17 (31)

new national parks were created that same year (Díaz-Briquets, 1996). Additionally, the *Ley of Repoblación Florestal* (Forest Regrowth Law) regulating timber production (using mostly exotic species) and the captive breeding program for the endangered Cuban crocodile (*Crocodylus rhombifer*) in the Zapata Swamp also began during 1959 (Targarona et al., 2010).

After the end of diplomatic relations with the United States, Cuba aligned with the Soviet Union, which became its primary trading partner for the next two decades. During this period (1960–1980), Cuban agriculture became one of the most industrialized in Latin America, relying on high levels of inputs and polluting water, soil and air (Levins, 1993; Rosset, 1997). Ironically it was during this same period when Cuba started to develop its conservation science. Samerk (1968) pioneered early attempts to classify and preserve Cuban biodiversity and Miller (1974) developed the scientific basis for the Cuban network of protected areas. In turn the National Forestry Policy was established in 1977 (Díaz-Briquets, 1996).

After the Berlin wall fell, marking the end of the Soviet Bloc, Cuba lost its main trading partner. Gross domestic product fell by 35% from 1989 to 1993, devastating Cuba's economy and food security in what is called the Special Period (Altieri et al., 1999). Petroleum, industrial fertilizers and pesticide imports fell more than half between 1989 and 1992, making the island shift to an alternative agriculture model (Levins, 1993).

In 1992, the National Forest Action Plan was established in association with the Food and Agriculture Organization of the United Nations (FAO) United Nations, which made modifications to the initial proposal presented in the 1992 Rio Summit. The Plan is an effort to promote Cuba's forests by means of protection, recovery and sustainable management of forest products and by strengthening research and training institutions through 18 programs. This program had a budget of 62 million Cuban pesos (US$ 2.58 million) with additional foreign assistance amounting to US$ 34.7 million.

In July 1997, Law 81 gave the legal means to implement a set of policies, laws, regulations and for environmental protection. Decree 201 in 1999 gave guidelines for the establishment and management of protected areas (Lindeman et al., 2003). Furthermore, in 1998, the National Assembly approved the Forestry Act aiming at preserving and restoring forest in 27% of Cuba (Lambert, 2008).

Another remarkable advance in Cuban conservation science and policy is the Vth National Report to the Convention of Biological Diversity (Republic of Cuba, 2014). This report, produced by a team of 121 experts from different institutions, focusing on Cuba's biodiversity status, protection and threats, management strategies, environmental education and governance. The 276 page report is an integrated, comprehensive and nuanced analysis of Cuban conservation status from species to ecosystems level (see major findings in the supplementary online material). Furthermore, the report set the basis for future prospects for Cuban conservation, proposing an increase in protected areas to 30% by 2020 (Republic of Cuba, 2014). This plan seems ambitious, as in 2016, only 12.4% of the terrestrial area was strictly protected (Protected Planet Report, 2016).

Recently, the National Plan for the Conservation and Management of Chondrichthyes in the Republic of Cuba (2015), a government action in line with FAO Technical guidelines for sustainable fisheries, reviewed the status of shark populations, major threats, and defined the priorities actions for shark and rays conservation and sustainable management. This plan is an example of effective partnership among Cuban local NGOs and associations, researchers, national government and international NGOs.

Also in 2015, Barack Obama visited Cuba as the first US president in office to step on Cuban soil in nine decades, improving diplomatic ties between the two countries. The Obama's administration removed visa obstacles and permissions for sharing data, resources and knowledge (Stone, 2015). However, the current US president Donald, Trump has promised to roll back the warming of US-Cuba diplomacy.

Furthermore, the US State Department has recently withdrawn significant part of its diplomatic body out of Cuba after many diplomats has fallen ill due to unknown causes. (https://www.nytimes.com/2017/10/03/world/americas/us-cuba-diplomats.html). Hence the future of the embargo is uncertain.

3. Agroecology

During the decade of the 1990s Cuba experienced a time of severe economic hardships following the dissolution of the Soviet Union. Cuba responded to the challenge by developing a unique model of agriculture based on mixed-farming, self-sustainability, diversification and decentralization (Altieri and Funes-Monzote, 2012). This involved organic fertilizers, biological pest control and application of local traditional knowledge (Altieri et al., 1999). These efforts resulted in the lowest average input consumption (such as fertilizer) and associated greenhouse emissions per farmed area of any country in Central America and the Caribbean region, according to the FAO (Table 2).

Cuba accounts for lower levels of greenhouse gases per farmed area than the Caribbean and Central America countries average (Table 2). Nevertheless, if countries emissions are ranked, Cuba occupies an intermediate position. This may be due to the fact that some of its neighbors emit even lower levels of greenhouse gases, possibility because Caribbean countries have small relative farmed areas, mostly relying on agricultural imports (such as the Virgin Islands, Antilles, Barbuda, etc.).

By the beginning of the 21st century Cuba had a well-established agroecological program based on sustainable mixed-farming, diversification and decentralization (Altieri et al., 1999). The city of Havana is an example of well-developed urban agriculture systems, with around 35,000 ha of urban gardens in more than 8000 parcels (Altieri et al., 1999). These systems involve use of hydroponics, rotated and mixed cropping systems, integrated pest management through ecological control, and biofertilizers. Home gardens in rural and urban areas are grown based on highly planned agrobiodiversity, with more than hundred cultivated species which are used for subsistence and traded in government communal cooperatives (Buchmann, 2009; Wezel and Bender, 2003). The management of these agroecosystems is constantly being improved by linking scientific and traditional knowledge in an adaptive and dynamic way (Leyva Galán et al., 2000; Leyva Galán, 2003).

In developing Cuban agricultural policy, the country has worked in multiple directions from top-down policies to grassroots local programs, and from urban to rural agroecological development. The widespread use of organoponics proposed by the government in 1987 and the conversion of large farms into state owned popular cooperatives are examples of top-down policies. On the other hand, grassroots and bottom-up movements have played a central role in the survival of Cuba during the Special Period and in building the sustainable basis of its society, such as the farmer-to-farmer development of sustainable technologies in farming (Rosset et al., 2011), as well as development of a wide variety of urban agriculture systems with different ownership regimes from individuals to communal (Altieri et al.,

1999). Despite this agroecological development, some paradoxes surround Cuban agricultural experiences and policies. For example, there have been significant efforts to revive industrialized/intensive agriculture systems (Altieri and Funes-Monzote, 2012).

How well these agriculture/food systems are able to support Cubans without the need of food import is a matter of controversy (Altieri and Funes-Monzote, 2012). However, Cuba's imports are small compared to other American countries. In 2010, Cuba had a value of 152 in its Import Value Base Period Quantity per capita (an index that measures the relative import quantity of crops and livestock, primary or processed) which is about three times lower than the average for Central America (497.9) and the Caribbean Region (497.4) (FAOSTAT, 2015). Even with these low food imports, Cuba has a high degree of self-sustainability regarding food security. Undernourishment affects only 5% of the Cuban population in 2014, less than half of the average of American countries according to the World Bank (2014) data base (data.worldbank.org/indicator).

4. Forest recovery

By the 1960s, only 14% of the Cuban forest area remained (Díaz-Briquets, 1996), but since then, forest policies have promoted continual forest restoration and conservation. Between 1960 and 1970, 299 tree nurseries were established and 348 million trees planted (Jiménez, 1972), most of them were of exotic genera such as *Eucalyptus* and *Pinus*. After then, species diversification was adopted, mostly due to the efforts of the demands of the Botany Institute (Díaz-Briquets, 1996). Reforestation programs also offered many employment opportunities to the rural population (Díaz-Briquets, 1996).

In 2010 all of Cuban forests were owned by the state, 22% of them within protected areas and 82% subject to management plans (many of the parks have management plans, therefore these categories may overlap in some areas), which represents a high degree of governmental protection and management (GFRA, 2010). Cuban public forestry institutions count with 2619 professionals, which is more than the total of all equivalent personnel in other Caribbean nations (1527 persons) (GFRA, 2010). Additionally, Cuba has higher quality education on forest disciplines, having more graduate students and master students than the sum of all its Caribbean neighbors. Cuban employment in the forestry sector, both in timber industry and in managing protected areas, constitute the largest in the Caribbean (GFRA, 2010).

These long standing and multiple forest policies are associated with a large scale forest regrowth inside and outside parks. Using the dataset on forest area from the Global Forest Resource Assessment (GFRA, 2010), we conclude that Cuba's native forest cover has increased by 39% over the last 20 years, which represents the second largest net rate of forest regrowth per country in the world (Fig. 2), after Puerto Rico, the first in the rank. Native forest cover increased by 673,000 ha between 1990 and 2010 according to GFRA (2010) estimates. This corresponds to total sequestration of 226 million tons of carbon dioxide in biomass (GFRA, 2010) at a rate of 10.277 million tons of CO_2 per year (FAOSTAT). Much of the increase in forest is associated with mangrove restoration. The government's efforts preventing logging and the direct rehabilitation of mangroves have increased the ecosystems area and as well as its health and quality for wildlife (Republic of Cuba, 2014).

We also used woody cover loss and gain estimates between 2000 and 2012 produced by high resolution (30 m × 30 m) forest maps (Hansen et al., 2013). According to this dataset, in twelve years, Cuba gained 22.7 and lost 17.25 thousand hectares of tree cover (this includes planted and native forest), and thus is the only country among Caribbean and Central America to have a positive gain/loss ratio (Fig. 3). We then compare how much forest have increased or decreased inside parks with forest dynamics out-side reserves (anthropic matrix) by overlapping protected network maps for 2014 with wood-cover gain/loss from 2000 to 2013 (Hansen et al., 2013) obtained at https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html. Map of parks included national parks, ecological reserves, biosphere reserves, wildlife refuge and RAMSAR sites for wetland protection.

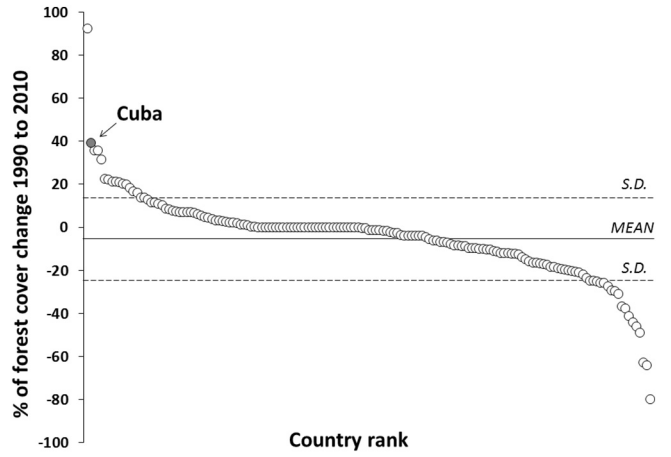

Fig. 2. Percentage of native forest change from 1990 to 2010 in the world by country, highlighting Cuba (the figures exclude planted forest) according to the GFRA dataset. Solid line is the average and dashed lines are the standard deviation.

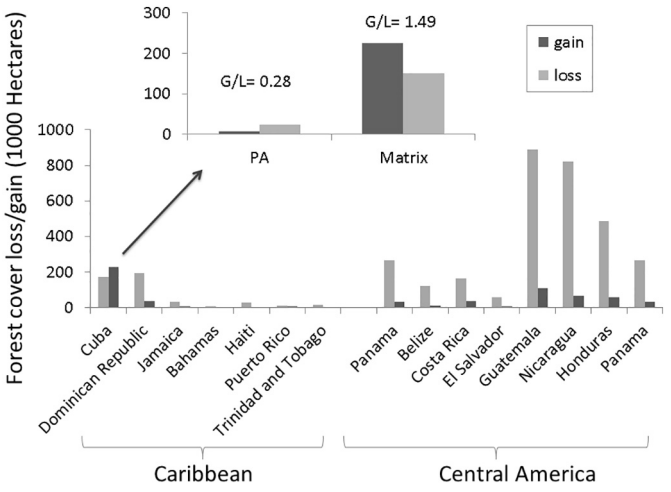

Fig. 3. Bottom figure shows forest cover loss/gain (thousand hectares) from 2000 to 2012 according to high resolution world forest mapping (Hansen et al., 2013). Top figure shows the ratio of forest gain and loss in Cuba between 2000 and 2013 inside parks (PA) and outside reserves (matrix) according to high quality wood-cover maps, and the gain/loss ratios (G/L) inside parks and in the matrix.

Our data points out for the fact that most of forest recovery occurred in the matrix, although previous authors have associated Cuba's forest regrowth with the establishment of parks (Díaz-Briquets, 1996). In fact, net deforestation has been larger than forest regrowth inside protected areas, while forest gain was larger than loss in the matrix, as shown by the loss/gain ratio (Fig. 3). Inside parks, area of forest loss was around one third of the area of forest gain, while forest growth exceeded deforestation in about 50% outside parks.

It must be noticed that these calculations refers to tree cover maps (not only forests), therefore it does not distinguish between natural and human-caused losses (e.g. hurricanes vs. forest clearing for agriculture). Furthermore, this cannot be taken as a measurement of park effectiveness in promoting forest regrowth or avoiding deforestation, as such analyses should take into account drivers of forest change at multiple scales (such as distance from cities, slope, soil fertility, proximity to farmlands, ect.). Nevertheless, the high positive ratio of gain/loss and the forest net increase in the matrix is notorious and can be an indication of matrix recovery based on ecosystems and biodiversity friendly managements.

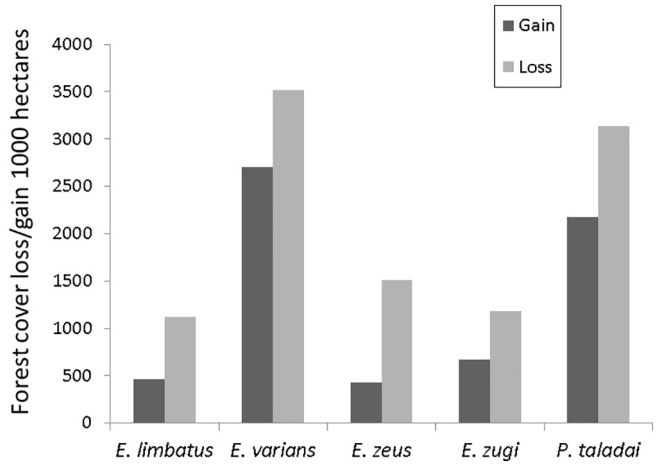

Fig. 4. Forest cover loss/gain (thousand hectares) from 2000 to 2013 within the range of endangered endemic anurans (*Eleutherodactylus varians*, *E. zeus*, *E. zugi*, *E. limabtus* and *Peltophryne taladai*).

To quantify how nationwide forest dynamics have affected biodiversity, we selected five species of endemic forest-dependent amphibians, each considered threatened at some degree by the IUCN, and measured how much of their distributional ranges has experienced woody cover loss or gain between the years 2000 and 2013 (Hansen et al., 2013). The geographical range maps of *Eleutherodactylus zeus*, *E. zugi*, *E. limbatus*, *E. varians* and *Peltophryne taladai* were obtained from the IUCN website (http://www.iucnredlist.org/technical-documents/spatial-data). The first two are considered "Endangered B1ab(iii), while the others are "Vulnerable B1ab(iii)" and all of them inhabit different kinds of forest habitats (IUCN, 2016). Contrary to the pattern seen overall in Cuba, within the species ranges, forest loss was larger than forest gain (Fig. 4). In the worst case, within *Eleutherodactylus zeus range*, forest loss was more than three times the area of forest increase during 13 years. Therefore, even though the island has suffered a positive net forest gain, habitat quality and extension has declined for forest dwelling species of conservation concern. This shows that deforestation still occurs in areas of high richness of endemics, putting them at further extinction risk.

5. Conservation advances and challenges

Cuban advances in biodiversity conservation includes a set of policies promoting biodiversity friendly agriculture, fostering forest growth, preventing deforestation and increasing strictly protected network. Furthermore, species-specific conservation plans were also important for conserving endangered species. All of these policies have acted increasing habitat extent and quality for plant and animals, maintaining or recovering landscape connectivity, providing ecosystems services and promoting in situ and ex situ species protection. We discuss each of these sets of strategy and how it influences biological conservation in Cuba.

5.1. Protected areas

From the 1930s up to now, the Cuban protected area network has been expanding in pulses, with boom periods interspaced by hiatuses of no significant advance. The revolutionary government increased the protected area network in the first year of the revolution (Díaz-Briquets, 1996), followed by two decades with no significant increase. The consolidation of the SNAP (National System of Protected Areas) during the late 1990's led to the creation of 30 parks, increasing terrestrial protected area from 4.2 to 6.5% of land area and marine protected shelf area from 1.3 to 2.8% of the between 1998 and 2002 (Fig. 5). The most significant increase in protected areas took place between 2009 and 2010, when the protected terrestrial network doubled from 6.2% to 12.5%, shortly after Raul Castro assumed power.

The marine protected network was also enlarged from 2.7 to 7.6% during the same period (IUCN). Although these numbers are still relatively small, the marine reserve network is equivalent to 61% of the total protected area of the Caribbean biodiversity hotspot (Mugica, 2009). By 2007, the National System of Protected Areas (SNAP) covered 85.3% of the endemic flowering plants and 96% of the endemic fauna species, thus having relatively complete representation within its area (Hernadéz, 2007).

5.2. Matrix biodiversity-friendly management

Out-side protected areas, matrix managed through low intensive agricultural mosaics have conserved significant levels of diversity, maintaining ecosystem services and promoting landscape connectivity. Although there is dearth information about how biodiversity respond to matrix management in Cuba, the few studies support the hypothesis that anthropogenic landscapes holds high biodiversity levels and maintain landscape connectivity among habitat patches due to agroecological matrix management.

(Perfecto et al., 2009). For example, many globally threatened birds are found in low-intensive agricultural landscapes such as the *Colaptes ferninada* (Ferdina's Flicker), *Psittaca euops* (Cuban parakeet), *Tachycineda cianeoviridis* (Barhamas Swallow) *Vermivora bachmanii* (Bachmans's Warbler) and *Setophaga cerula* (Cerulean Warbler) (http://datazone.birdlife.org/species/factsheet).

Chondrohierax wilsonii (Cuban kite) is a critically endangered bird that was once common in the entire island and is currently restricted to the extreme east of Cuba. Habitat loss by logging, habitat conversion for agriculture, and the decline in snail populations of which the Cuban Kite depends, is thought to be the main reason of the decline according to Bird Life International. (http://datazone.birdlife.org/species/factsheet/cuban-kite-chondrohierax-wilsonii/text).

Low intensive rice plantations without the use of pesticides and high habitat heterogeneity, associated with increase in a national wide wood-cover could benefit this species by increasing habitat extent and quality, as well as its food resources.

The Cuban parakeet (*Psittaca euopds*) was once one the most common endemic species is now restricted to small, isolated and declining populations (http://datazone.birdlife.org/species/factsheet/cuban-parakeet-psittacara-euops). It inhabits semi-deciduous woodland, palm-savanna habitat, trees on cultivated land and the edges of woodland, and depends mostly on dead palms (such as *Roystonea regia*, *Sabal palviflora* and *Copernicia*) to build their nests (http://datazone.birdlife.org/species/factsheet/cuban-parakeet-psittacara-euops/text). Therefore, the increase in forests and agroforestry systems may benefit this species by increasing habitat area, nesting site availabilities, food resources and landscape connectivity.

Live fences also help maintain the diversity of bats in Cuba's landscapes, possibly increasing habitat supplementation in the matrix (sensu Tubelis et al., 2004) and landscape connectivity (Pozo et al., 2014). This high bat diversity and abundance maintains seed dispersal, which may in turn, affect regeneration of degraded areas. Low intensively gazed areas and farms that are being converted to agroecological management are also known to hold high levels of soil macrofauna biodiversity (Terry et al., 2015; Chávez Suárez et al., 2016).

Another example of Cuban conservation uniqueness is the seamless approach developed to integrate waterbird conservation and rice agriculture. Rice cultivation is the second most important crop after sugarcane in Cuba. The most extensive rice production regions are in close proximity to natural wetlands, facilitating the waterbirds' use of the rice fields as feeding areas. Further, the general lack of pesticide and herbicide use promotes high levels of vertebrate and invertebrate biodiversity (Mugica et al., 2006). Consequently, water bird populations thrive in the rice-producing regions of Cuba. However, the recent

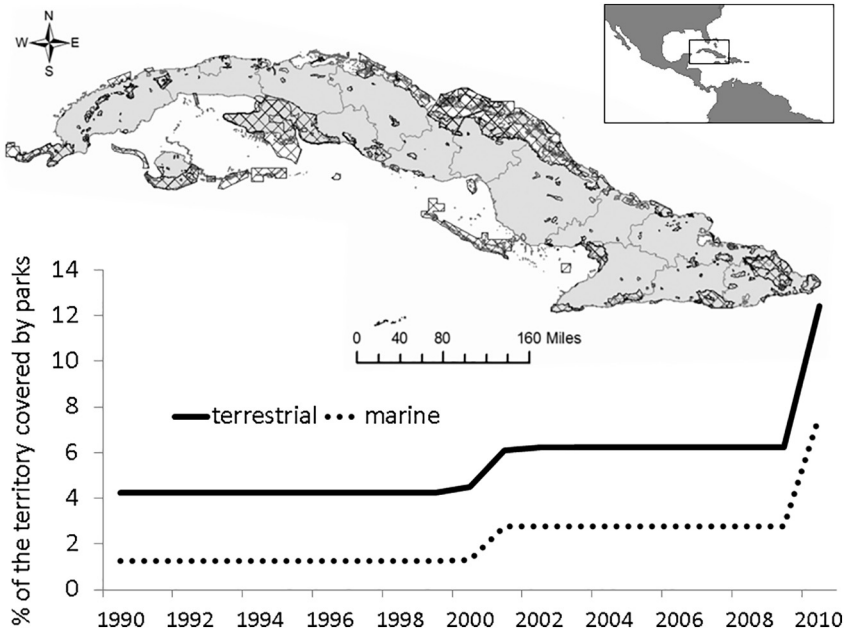

Fig. 5. Proportion of the terrestrial and marine Cuban territory covered by reserves in the recent years, according to the World Bank database (http://data.worldbank.org/). Map of the Cuba's protected network for the year 2013.

efforts by some sectors to bring back the intensive agriculture to Cuba (Altieri and Funes-Monzote, 2012), may further increase threats to this biodiversity, stepping back on sustainability and conservation advances.

If Cuba adopt intensive agriculture pathway, habitat homogenization, generalized used of pesticides and reduction of the matrix permeability to species movements will have negative effects on animal and plant communities, as it did in other tropical countries such as Brazil (Goulart et al., 2013). Nevertheless, we find this rather unlikely by the awareness of Cuba's scientists, general public and decision makers about environmental and conservation issues.

5.3. Species-specific programs

Additional success stories in conservation of Cuban biodiversity include efforts to protect and manage some of the most charismatic endangered species of the island archipelago, including the Cuban parrot (*Amazona leucocephala palmarum*) and Cuban sandhill crane (*Grus canadensis nesiotes*). Public education campaigns and habitat management efforts on the main island of Cuba and on the Isla de la Juventud have succeeded in protecting breeding populations of both species (Gálvez-Aguilera et al., 1999). The captive management of the Cuban crocodile, which is considered critically endangered by the IUCN (IUCN, 2016), is also noteworthy. The program began in 1959 aiming at selling meat and stuffed animals, and but moved to a conservation-oriented approach in the following decades. Today, the program aims at conserving this species, emphasizing advances in physiology, ethology, hematology, animal husbandry and veterinary knowledge (Targarona et al., 2010). There has been also substantial improvement in comprehension of the crocodile's ecology, biology and conservation in situ. According to genetic studies carried out by Cuban scientists, half of the wild population and 16% of the captive population consist of hybrids between the Cuban and the American crocodile. Consequently, hybridization is being the greatest threat to the former (Milián-García et al., 2015).

6. Conservation challenges and biodiversity threats

Despite of the overall conservation and sustainability advances, Cuba's environmental governance faces many challenges. Parks and areas of high levels of endemism suffer from forest loss and fragmentation even though the forests have increase in most parts of the country, as mentioned above. Among the drivers of deforestation, tourism activity has been particularly important (Díaz-Briquets, 1996). Tourism leads to habitat loss and fragmentation by direct impact of infrastructures and facilities such as hotels, roads, bars, restaurants. It also fosters the expansion of farmlands, mining, industry and cities, as well as increases waste and pollution caused by these activities. Tourism is also an important driver of habitat loss and degradation of non-forest environments, such as sand-dunes, wetlands and corals. A research in the Cayman Island (Tratalos and Austin, 2001) showed that scuba diving increased the amount of dead corals and coral rubble and Cuba's corals are believed to suffer similar impacts from this type of tourism.

Furthermore, tourism is in booming in the island and in 2016 the country hit its record on tourist influx, accounting for more than 4 million international tourists, 13% more than 2015 (http://agenciabrasil.ebc.com.br/internacional/noticia/2017-01/cuba-bate-recorde-turistas-em-2016-com-4-milhoes-de-visitantes). Therefore, environmental impact of tourism is predicted to keep on rising in the years to come.

Another important issue is native population declines and ecosystems changes caused by invasion of alien plants and animals. A review on the impact of mammal introduction in Cuba showed that invasive species is one of the drivers of vertebrate declines (Borroto-Páez, 2009). Among the 29 exotic mammals, the black rat, dogs, cats, mouse, mongoose, pig, goat, brown rat and cattle are particularly impactant species (Borroto-Páez, 2009). Twenty six species of non-native reptiles and amphibian occur in the Cuban archipelago, most of them have high potential impact on the local fauna (Borroto-Páez et al., 2015). Additionally, invasive plants are important drivers of habitat degradation and specific protocols for monitoring, managing and eradicating these plants have been developed in Cuba (Oviedo et al., 2012).

Overexploitation is another driver of species loss in marine and freshwater ecosystems. Overfishing has already pushed down most populations of harvested species, such as fishes, mollusks, and crustaceans (Díaz-Briquets, 2012). According to the recent report on Chondrichthyes conservation and management, production of sharks and rays (metric tons) has declined in two thirds from 1985 to 2015, mainly due to overfishing (Republic of Cuba, 2015). Nevertheless catchment reduction in the Special Period, caused by smaller fleets and lack of oil, has significantly alleviated the pressure on fisheries (Díaz-Briquets,

2012). Moratorium of species catchment, such as Florida stone crab (*Menippe mercenaria*) during the 1990s, has also played important role in the recovery of this species in Cuba (Certuo, 2015). Nevertheless, current catchment levels could roll-back this scenario, leading to a decline in crab populations (Certuo, 2015).

Climate change is also major threat to the Cuban biodiversity. The V Report on Biological Conservation (2014) reviewed sixteen studies assessing the effects of climate change on Cuban biodiversity, including reefs, sea turtles, lobster production (*Panulirus argus*), phytoplankton, mangroves communities, sponge assemblages, carbon retention by marine biomass, and fishing stocks. Distribution shifts predicted for 32 frog species, 30 of which will have lost 85% by 2050 and 97% until 2080. Significant reduction in reptile, mammal and bird distribution ranges is predicted. Dozens of wading birds species will suffer significant habitat loss due to sea raise, including populations inhabiting five RAMSAR sites. Many tree species will suffer habitat loss due to sea inundation (Republic of Cuba, 2014).

Climate change indirect effects includes in the increasing in frequency and intensity of extreme environmental events such as hurricanes and tropical storms. Hurricanes are known to cause habitat loss and degradation (such as deforestation and by destroying coral reefs) affecting species directly and indirectly. The Cuban Parakeet depends on dead palms to build nests, which are destroyed or damaged by storms and hurricanes, causing nest failures and population declines (http://datazone.birdlife.org/species/factsheet/cuban-parakeet-psittacara-euops). Hurricanes are also one of the major threats to endangered waterbirds (Blanco-Rodriguez et al., 2014). Furthermore, storms and hurricane are already becoming increasingly more frequent in the last decade due to global warming (Coumou and Rahmstorf, 2012), and the year of 2017 has accounted for unusual higher number of extreme climatic events in the Caribbean. Recently, the Irma Hurricane has stricked many islands in the Caribbean including Cuba, causing 10 human fatalities (http://www.aljazeera.com/video/news/2017/09/hurricane-irma-death-toll-rises-10-cuba-170912074718033.html) and certainly impacting other species and their habitats.

7. Lessons from Cuba and future challenges

Cuba holds an extremely rich and endemic biodiversity and ecosystems. We show evidences that point out for the effectiveness of overall Cuban sustainable and conservation policies. Agroecological matrix management; maintaining high planned and associated biodiversity managed with low levels of agrochemicals; long-standing reforestation inside and out-side parks associated to strengthened forest governance; increase in terrestrial and marine protected areas; active species-specific programs for ex situ conservation and environmental education. All of these policies have benefited overall species and habitat conservation in the island, and could be applied in other tropical nations. These multiple conservation governance has relied on a tight relationship between academia, farmers and decision makers. Yet, there are many challenges for conserving this unique biota. As future prospects, Cuba will face increasing anthropic pressures and environmental changes. Of particular importance is increasingly international tourism influx and climate change.

Despite of the blockade's influence on Cuban scientific development, its advances in ecological conservation are notable. Under the pressure of partial isolation, Cuba has developed innovative and unique environmental governance that has been poorly represented in the mainstream conservation literature.

In 2015, the US president Barack Obama visited Cuba, marking the re-establishment of diplomatic relations after more than half of a century of estrangement between the countries. Some US politicians claimed that the embargo was close to an end (http://thehill.com/policy/national-security/270575-senate-chairman-sees-possible-end-of-cuba-embargo). Despite of this, the current US administration predicts new restrictions as well as reversal of the opening with Cuba (http://edition.cnn.com/2017/05/30/politics/trump-cuba-policy/index.html). We believe that conservation science and practice would gain from the end of the embargo and that freely exchanging experiences with Cuba would benefit biodiversity. Whilst forest, corals and their associated biota cannot wait for such a political decisions, international conservationists and biologists should learn from Cuban experiences. Conversely, Cubans have much to gain from interacting with other nations. This will surely bring great benefits to conserving the environment of our planet.

Conflict of interest

The authors declare no conflict of interest.

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